"The Measurement of All Things"

Now it's your turn to be the Aerospace Researcher in our online project. Get your free software in step 1 before moving on to conduct your research in steps 2 and 3. Click on "READY!" to begin.

Please note: This site uses white text on a dark background. If the text does not appear when printed, configure your browser to print all text as black.

Download Your Own Wind Tunnel Simulation!

Learn About Lift!

Become a Wind Tunnel Researcher!!

"The Measurement of All Things"

Do you want to try being a NASA researcher? Before you get started you'll need to set up your computer with the right measurement tools.

1.) Download your own wind tunnel simulation from the NASA Glenn Research Center in Cleveland, Ohio. When you click on the buttons below, a new browser window will open (it may even cover this one!) and will connect you to NASA Glenn's Learning Technologies Project web site. Follow the instructions to get FoilSim up and running on your computer. When the download is complete, close that window. You will then be back here and ready to move on to the fun stuff!

2.) For teachers and parents, we have made a printable version of all the pages contained within this online project. This document might help you as you prepare to use this CONNECT activity with your students or children. The printed version is an Adobe PDF document which requires the free Adobe Acrobat reader (this link will open up a new browser window). If you have this plug-in installed, download the document here. It is a 270KB document, so it may take a few minutes to download.

You are now READY and can go back to the main screen to move on to step 2 . . . SET!

"The Measurement of All Things"

Before NASA researchers use a wind tunnel to perform tests and gather data, they do preliminary research, plan the test, and figure out what they will be trying to measure. Before *you* start *your* test, we should also prepare. First, let's figure out what we need to make a plane (or anything else for that matter!) fly.

Why aren't you flying right now? One reason is that your weight is holding you on the ground. Weight is a ***force*** that pushes a plane towards the ground just like it always pushies you toward the ground!

Let's do a quick calculation based on weight. . . Enter your weight in the box below and then click the button to continue:

How much do you weigh? 110 lbs

CONTINUE

"The Measurement of All Things"

Ok, the weight you provided is **110** pounds (lb). Here at NASA CONNECT we use the metric system of measurement. In metric units you weigh **49** kilograms (kg). To do this conversion yourself, all you need to do is multiply your weight in lb. by 0.454; then you'll have your weight converted to kg!

To fly (or at least get off the ground) your body needs to experience a force that is a little more than **110** lb (**49** kg). This force must be in the opposite direction of gravity - pushing or pulling you upwards. Why? Because a force in this direction would help cancel out the force caused by gravity (your weight). You're probably wondering when we're gonna' start talking about planes aren't you. . .

How much "lifting" force do you think is needed to lift a Boeing 747-400 jumbo jet into the air? (Hint: the force would be just a little more than the weight of the jet, but in the opposite direction. Try to guess the weight of the 747. That will be the lift force!) Type your guess in the box below, but remember, we're working in kilograms now! If it's easier for you to guess in pounds, just remember to multiply by 0.454 to get kilograms! When you've entered your guess, click continue to move on!

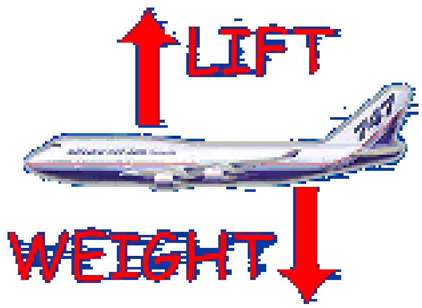
How much does the 747-400 weigh? 10000 kg

CONTINUE

"The Measurement of All Things"

Well, you'll need a little more force than that - with a weight of 396,900 kg, your force of 10000 kg would keep that 747 resting firmly on the ground! You were about 386900 kg too low!

We'd need to have that much force (396,900 kg) pushing up on the plane to get it off of the ground and into the air. In other words, we would need a little more than 396,900 kg of "lift" to overcome the weight of the airplane so it can fly.



The main lift-generating features of most airplanes are the wings. How do wings create lift? It all starts on the runway when the pilot fires up the plane's engines. The engines causes the plane to begin moving on the runway. As the plane's wheels roll across the ground, air rushes under and over the plane's wings. Believe it or not, this airflow around the wings creates the lift that will allow the plane to fly! Come on, let's see how! We'll get two old guys to help us out. Let's go meet them!

(P.S. You can visit the Boeing website if you want to find out more details about the 747!)

"The Measurement of All Things"

Meet Sir Isaac Newton, an English mathematician and physicist who lived between 1643-1727, one of the greatest scientists of all time. He made tremendous contributions to our understanding of the world and universe. He explained motion by using three different "laws," but we're interested in only the *third* one right now.

Newton's Third Law of Motion is, "*To every action there is an equal and opposite reaction*." Don't worry, this isn't as difficult as it sounds! Think about it this way . . . If you sit on a table, you are actually pushing down on the table with the force of your weight. The table is pushing back up on you with an equal force. If it didn't, you'd fall right to the ground! Newton's Third Law means *equal but opposite* forces are occurring!

"The Measurement of All Things"

Meet Mr. Daniel Bernoulli. Do you like the hairdo? Give him a break; he lived in the 1700's! Among the many discoveries this Swiss mathematician and scientist made was what we know today as Bernoulli's principle: "When air (or any fluid for that matter) moves *faster*, its pressure (force applied over an area) will *decrease*." Knowing this, what do think will happen to the pressure created by air that is *slowing* down?

If you guessed the pressure will *increase*, you're right! ***Fast air = low pressure*** and ***slow air = high pressure***. If you want to see that Bernoulli's principle really works, click below on "Let's Experiment!" . It's a project you can try at home or in class!

Let's Experiment!

If you're ready to see what Bernoulli's principle has to do with keeping a 747 in the air, let's move on. (Have you figured out how Bernoulli and Newton can help us with our problem of making something fly yet?)

CONTINUE

"The Measurement of All Things"

Bernoulli's Principle
Ping-Pong Ball Experiment

Experiment:
Get a hair dryer and a ping-pong ball. Turn the hair dryer on high. (Use the cool air setting so you don't burn yourself!). Place the ping-pong ball into the stream of air. What happened to the ball? Did it blow away?

As you tilt the hair dryer gradually to the left and right, forward and backward, what happens to the ping-pong ball? You should observe that it actually stays in the air stream (at least until you tip it too far!). Why? Bernoulli's principle explains what's happening. Think about it and try to come up with an explanation before reading the next paragraph.

Explanation:
The fast-moving air coming from the hair dryer creates much less pressure than the almost motionless (very slow-moving) air in the rest of the room. The hair dryer has created a cylinder of fast, but low-pressure air. As the ping-pong ball moves around within this invisible cylinder of air, it "bounces" off the wall of higher pressure created by the slow moving air within the room. The ball stays in the stream of fast moving air coming from the hair dryer. Mr. Bernoulli would have loved to see this experiment!

Extensions:

1. Can you think of other things that can be explained or understood by Bernoulli's principle?
2. Find more information about Bernoulli. Why was he interested in the relationship between airspeed and pressure?
3. Can you think of any other experiments that demonstrate Bernoulli's principle?

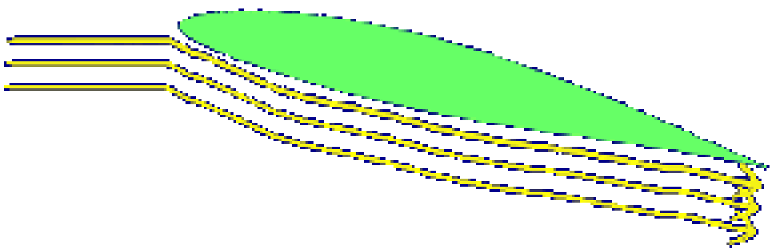
When you are ready to return to the main project, click the button below!

CONTINUE

"The Measurement of All Things"

So how can these two old guys, Newton and Bernoulli help us figure out how a 397,000-kg piece of metal stays in the air?

For starters, a plane's wings are designed to change the direction of the air that flows across them. Some air goes over the wing, and some goes under it. Some of the air flowing above the wing is pulled down, while some of the air passing under the wing is pushed down (see the illustration below). Newton's Third Law tells us that when the wing pushes or pulls the air down, the opposite will happen to the wing. . . it will be *pulled or pushed **up***! This upward force of the air on the wing is what we call **lift**! *(Factoid: The backward force caused by the air pushing on the wing is called **drag**.)*



And what about Mr. Bernoulli? Well, let's assume that the wing is actually experiencing an upward overall force (lift) as we saw above. The pressure applied above the wing (the force pushing down) must be less than the pressure applied below the wing (the force pushing up). Bernoulli's principle states that the air above the wing must be going *faster* than the air below the wing. If the air flowing *above* the 747's wing speeds up, the pressure on top of the wing *decreases*. If the air passing *below* the wing slows down, the pressure below the wing *increases* so there is more pressure below and less pressure above. Our lift is increasing!

Two different values tell us how well our wing is performing. We can measure either the *pressure* above and below the wing directly, or we can measure the *airspeed* above and below the wing!

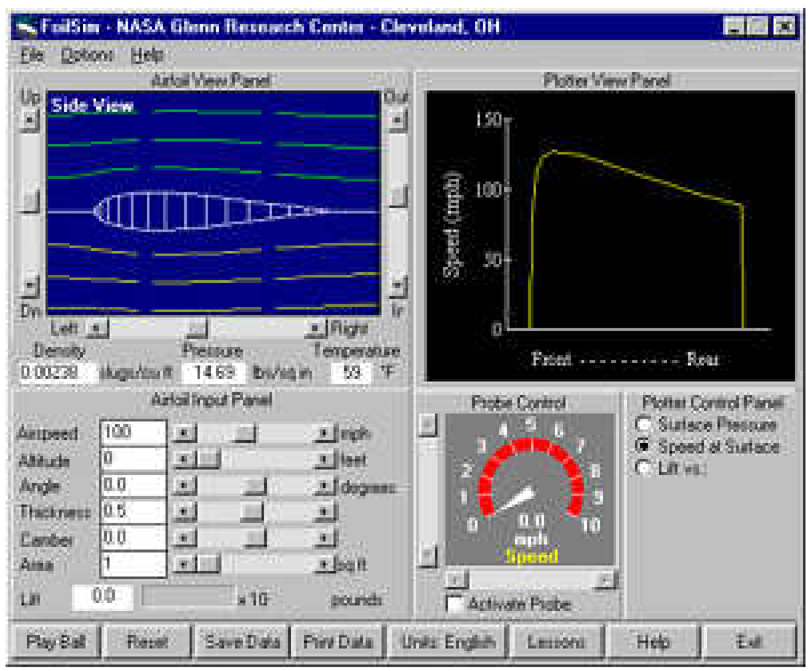
Now it's your turn to design a wing! With this little bit of background, you're ready for step 3, so lets ***GO***!

"The Measurement of All Things"

PROVE IT!

Now that you're an expert with Newton's Third Law and Bernoulli's principle, let's use FoilSim to see how they really work! (If you have don't have a clue about Bernoulli and Newton, take just a few minutes to go through the previous [Section 2, SET!] to help you understand what we're about to do. You'll have a lot more fun with this section if you do!)

FoilSim let's you run a wind tunnel simulation right on your computer! If you haven't already installed FoilSim, now would be a good time to visit [Section 1, READY!] to set it up. If you've completed both of the previous steps, go ahead and launch FoilSim. You should see a screen that looks like this:



You will want to have both FoilSim and this web site running at the same time for the rest of this project. If your computer is reasonably fast, you should be able to do that easily. If your system is a bit slow, you may want to find another computer nearby. You can run FoilSim on one computer and this web site on the other.

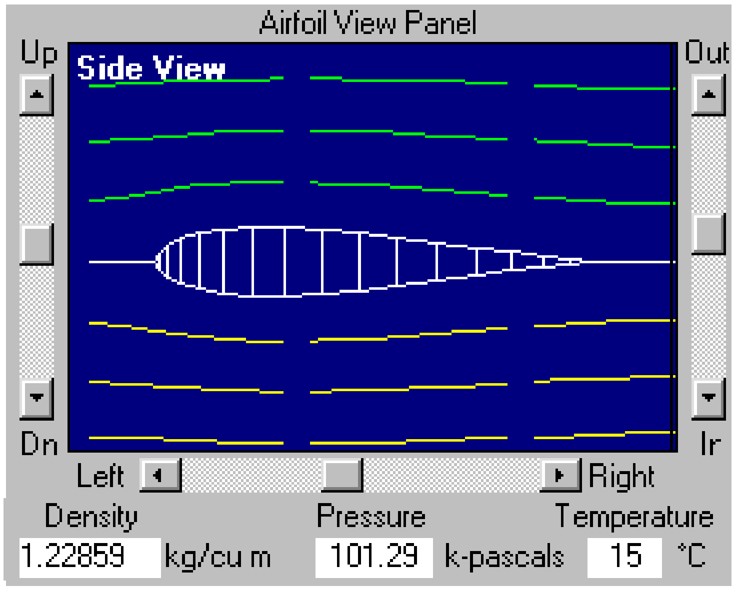
If FoilSim is not displaying metric units yet, click on the button along the bottom that says Units: English to change to metric units. In both FoilSim and this activity the follwing abbreviations are used:

m = meter, km = kilometer, hr = hour

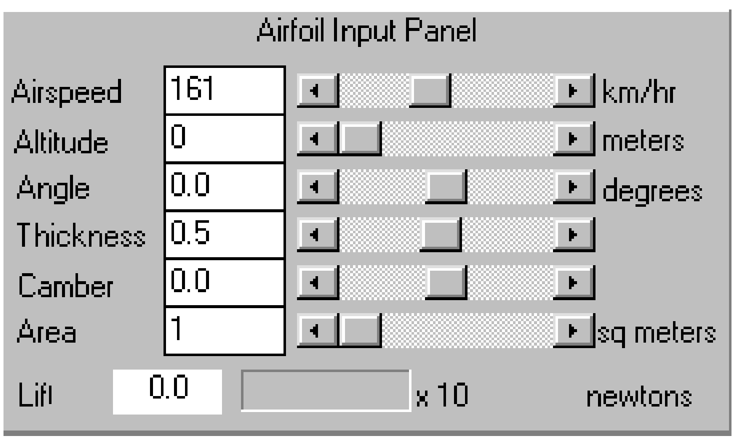
CONTINUE

"The Measurement of All Things"

For this investigation, we will focus on the ***left*** side of the FoilSim window. For now, ignore the graph and gauge on the right side of the screen. The upper left portion of the FoilSim screen is your test section, which contains the wing shape (or airfoil) that you will test. This area, called the ***Airfoil View Panel***, holds the wing still as air moves past it from left to right. It should look like this on your screen:



Imagine that someone cut through a wing from top to bottom. You are looking at it from the side. What you see is called a "cross section" of the wing. Air flows over (green) and under (yellow) the wing from the left side of the screen. FoilSim provides measurements and does some math work for you to determine how well your wing is performing. Notice also that the bottom of this window shows you the density of air, pressure, and temperature for the altitude at which your airfoil is being tested.



Below the Airfoil View Panel is the ***Airfoil Input Panel***, where you will control your test. You can change different aerodynamic variables, or *parameters*, to control the shape and testing conditions for your wing. FoilSim will report the amount of lift generated at the bottom of this panel. Make sure you notice the multiplier (x10, x100, x1,000, etc.) when recording your lift value!

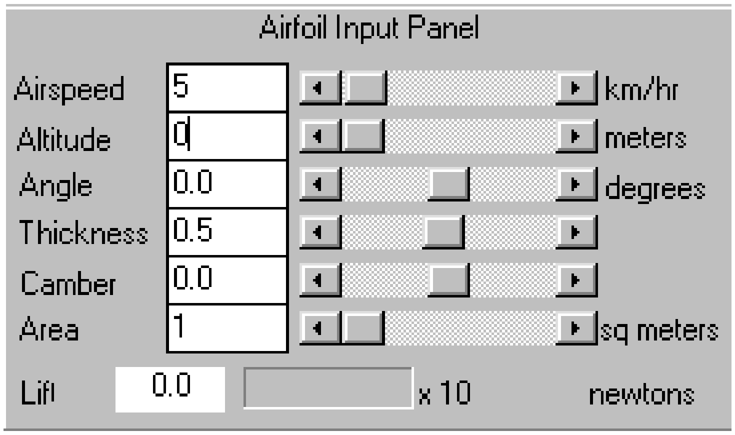
What is the current airspeed? To find out, just look in the white box to the right of the word "Airspeed." In our example, it is 161 km/hr (about 100 mph). To change the airspeed, you can either type directly in the box or drag the slider left or right. A plane usually starts off on the ground, doesn't it?

Why don't you simulate this by setting the airspeed to 0 now.

Once you have done this, click on the button below to move on.

NASA CONNECT

"The Measurement of All Things"

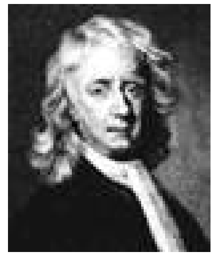


The altitude indicator is right below the airspeed indicator. Currently, you are testing your wing on the ground, at a height of 0 meters. Since you're barely moving, you are generating no lift. You can confirm that there is no lift by looking in the Lift window at the bottom of the left-hand column. Now that you're a little more familiar with the control panel, let's speed up the air and get ready to fly! We certainly need the air moving around the wing before any lift can be generated!

Set the speed to 100 km/hr.

Do you have any lift yet? Did you expect any? If we have a wing and air is moving past it rather quickly, why do you think that there isn't any lift? Once you think you have an answer, let's move ahead and fix this problem!

"The Measurement of All Things"

Why don't we have lift yet? . . . Remember Newton?  Remember Bernoulli?

Right now we have a wing that is the same shape on the top and bottom. It is also heading directly into the wind. Because of these two factors, all the forces acting on the wing are balanced. There is nothing to make the air above and below the wing move at different speeds. The forces created by the airflow above and below the wing are equal so no lift! Remember, to make Mr. Newton happy with our wing, we need to direct some air downward to create an upward force (Newton's Third Law). The air passing above the wing need's to move faster than the air below it before Mr. Bernoulli's principle will indicate that we have lift. So let's do it!

Change the angle to 5 degrees

- Type "5" in the angle box or move the angle slider.
- Did you produce any lift?
- If so, how much?

Change the angle to 15 degrees.

- What happens to the lift?
- What will happen if you set the angle to a negative value?

Give it a try! Set the angle to -10 degrees.

By tipping the wing up or down, you have *changed how the air flows over and under the wing* and generated lift. Now, before we move on let's see if you understand what's going on. With your wing at -10 degrees (type in -10 if you need to), the lift indicator should show that you have generated about -5.77x100 or -577 Newtons of lift. This is a negative value for lift, so you're not lifting at all! You are helping gravity push your plane into the ground! Think back to Bernoulli's principle to answer the following question:

With a lift value of -577 Newtons, where is the air moving faster?

○ over the top of the wing

◉ under the bottom of the wing

"The Measurement of All Things"

You're really getting this! You are correct - the air flowing under the wing is moving faster than the air above the wing. The slower air above the wing is pushing down with more force than the faster moving air below the wing is pushing upward. So the overall effect is a downward force on the wing.

Let's work on another way to create lift by *changing the shape of the wing itself*. The *curvature of the wing* is called ***camber***. You'll see that you can change the camber of your airfoil in the *Airfoil Input Panel*. ***Make sure you notice the multiplier** at the end of the lift box which is part of the lift value. (To help you notice when the multiplier changes, the lift indicator bar will change color)*

Leave the airspeed at 100 km/hr for now.

Set the angle back to 0. (Still no lift)

Enter in a few different values for camber.

- How does camber affect the shape of the airfoil?
- How does camber influence lift?
  (Hint: look at how the air flows around the wing
  and think about Newton's Third Law)

Enter a camber value that will give you a positive lift value.

Now increase the airspeed to 200 km/hr.

- What happens to the lift?

Increase the airspeed to 400 km/hr.

- What happens to the lift?

Here's another checkup to see if you understand how camber affects lift. . .

1.) **Increasing** camber will. . .

- ◉ increase lift
- ○ decrease lift

2.) **Decreasing** airspeed will. . .

- ○ increase lift
- ◉ decrease lift

"The Measurement of All Things"

Most excellent! This airplane design stuff is too easy for you! Increasing ***either*** the camber or the airspeed will increase the lift produced by the airfoil.

Take a look at your current lift value. What would happen if your plane were to climb into the air? (Have you noticed you've been on the ground all this time? Check your altitude indicator!)

Change your altitude to 1,600 meters (about a mile).

- What happened to the lift?

Change the altitude to 10,000 meters.

- What happens to the lift value?
- Does lift increase or decrease when the altitude increases?

To make up for reduced lift at higher altitudes, let's use a special "James Bond" feature of FoilSim. You won't find this on the next commercial flight you take with your family! What is this feature? Instantly expanding wings! In the *Airfoil Input Panel* look for the "Area" control. Your airfoil currently has an area of 1 meter. Imagine looking at your wing from the top, instead of the side. It would be pretty small - about the same size as the hood on most cars. Let's use our 007 trick to make our wing grow all of a sudden.

Increase the area to about 6 square meters.

- What happened to the lift?

Change the area several more times.

- How much effect does the airfoil's area have on the lift it generates?
- Is it a big effect or just a small one?
- *Why?*

take this last mini-quiz before starting your design project. . .

As a plane approaches an airport for a landing, it descends from its cruising altitude of 7,500 meters to an approach altitude of 500 meters. Considering this change in altitude, the lift generated by the plane's wings will. . .

◉ increase

○ decrease

"The Measurement of All Things"

You got it! As the plane's altitude decreases, the lift generated by the airfoil actually increases. Of course the pilot is doing other things to compensate for this. Reducing the airspeed by throttling back the engines, or changing the camber of the wings by using the flaps can reduce the lift. (Commercial planes can't change the surface area of their wings too drastically in flight!)

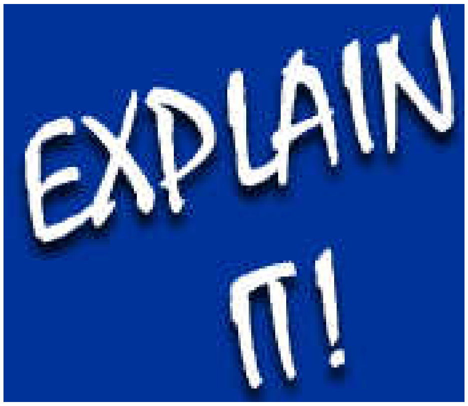
It looks like you're ready to create your own design. Click on the button below to get your assignment!

"The Measurement of All Things"

NASA has asked you to design an airfoil that will become the wing for an experimental plane. The amount of lift needed to keep the plane in level flight is 140,000 Newtons. (Remember, for level flight the angle equals 0!) The plane will reach a normal cruising speed of 300 km/hr and a cruising altitude of 10 km. Using FoilSim, create a design that will meet these specifications. Once you have designed your airfoil, enter in your design values in the table below. Also, record the lift value reported by FoilSim. These will be your NASA prototype design values. (Remember, use a 0 degree angle for your basic design).

Airspeed	300	km/hr
Altitude	10000	meters
Angle	0	deg
Camber	.5	
Area	20	sq meters
Lift	0	newtons

"The Measurement of All Things"



Now let's create graphs of how your airfoil performs under different conditions. (You'll need graph paper for this part. If you don't have any, you can download a printable version as a PDF document.) This step is probably the most important in your research because it will help you "see" what is happening. How do you go about making these graphs? Glad you asked! Keep all values the same as those in your NASA prototype. For each graph, change only one parameter (variable). Change the parameter in FoilSim and record the lift value at each step. Use the tables below to record your data for all three parameters.

Your NASA Protptype design values are

Airspeed = 300 km/hr	Camber = .5
Altitude = 10000 m	Area = 20 sq meter
Angle = 0 degrees	Lift = 0

Determine how your airfoil performs at these different altitudes: 0 meters, 500 meters, 3000 meters, 8000 meters, 12000 meters and 15000 meters.

Reset your altitude setting to the value of your NASA prototype design. Determine how your airfoil performs at the following speeds: 5 km/hr, 50 km/hr, 100 km/hr, 200 km/hr, 300 km/hr, 400 km/hr

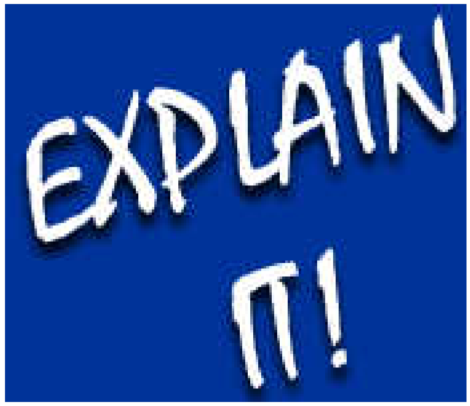
Reset your airspeed setting to the value of your NASA prototype design. Determine how your airfoil performs at the following angles of attack: level flight, 4 degrees, 10 degrees, 12 degrees, -9 degrees, -13 degrees

Altitude	Lift
0	0
500	0
3000	0
8000	0
12000	0
15000	0

Airspeed	Lift
5	0
50	0
100	0
200	0
300	0
400	0

Angle	Lift
0	0
4	0
10	0
12	0
-9	0
-13	0

"The Measurement of All Things"



The charts at the bottom of this page summarize the data you collected. If you have a printer, you may want to print these charts now. Otherwise, create your own charts on notebook paper.

Using graph paper, create three graphs, one for each set of data.

Use the graphs you create to answer the following two questions, keeping in mind that NASA researchers often try to describe things with mathematical relationships.

1. What do your graphs tell you about lift and its relationship to these three variables?
2. Do you see any mathematical relationship between lift and altitude/airspeed/angle? (An example of this type of relationship would be that doubling "X" doubles lift; "X" would be altitude, airspeed or angle.)

ALTITUDE (m)	LIFT
0	0
500	0
3000	0
8000	0
12000	0
15000	0

AIRSPEED (km/hr)	LIFT
5	0
50	0
100	0
200	0
300	0
400	0

ANGLE (degrees)	LIFT
0	0
4	0
10	0
12	0
-9	0
-3	0

CONTINUE

"The Measurement of All Things"

EXPLAIN IT!

The following questions are for further investigation. Discuss the possible answers with your class or family to help gain a better understanding of the aerodynamic principles you have learned about in this project. You may even want to use them in a classroom project.

1. Why does a plane's altitude influence the amount of lift generated by its wings?
2. Notice that FoilSim estimates the temperature at a given altitude. (Look in the lower left of the Airfoil View Panel Display). How and why does altitude influence temperature?
3. You saw that increasing the angle of attack (angle in FoilSim) increases lift. FoilSim stopped you at a maximum value of 20 degrees (and -20 degrees in the other direction). If you increased the angle more and more, would you reach a point when the lift would begin to decrease? (Hint: you may want to investigate "stall")
4. If increasing the area of a wing increases the amount of lift it creates, what would prevent aircraft designers from building huge planes that could carry thousands of passengers and packages? Why don't they just use giant wings?
5. You've probably already found it, but in the lower left corner of the FoilSim window is a button that says "Play Ball." Click on this button and investigate how a pitcher throws a curve- or screwball. (Baseball fans: what's the difference?) Explain how the air flowing around the baseball causes it to curve. Why is it a lot different for a pitcher to pitch a game in Cleveland, Ohio than in Denver, Colorado?
6. We've looked primarily at the wings of a plane. If you were an aircraft designer, what other aircraft elements would you need to consider if you were creating a plane? What are some tradeoffs that you might want to consider (i.e., more passengers = more weight = more fuel or shorter distances, etc.)

You might want to visit these other sites to learn more about aeronautics!

- NASCAR Wind Tunnel Testing
- NASA Langley's Kid's Corner
- The JAVA Virtual Wind Tunnel
- Aero Design Team Online
- NASA CONNECT Home Page

Thanks For CONNECTING with us.
Tell your friends about us, and we'll see you next time!